Appendix G

Detailed Cost-Effectiveness Analysis of Container Ships

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This appendix contains a more thorough discussion of the cost-effectiveness analyses conducted for container ships than what was provided in Chapter V. For brevity and clarity, Chapter V addressed NOx emissions reductions for container ships burning 0.1 percent sulfur distillate fuel, with the necessary electrical transformer located on the shore—the most likely scenario. Appendix G further addresses the reduction of other pollutants, the use of 0.5 percent sulfur distillate fuel, and the construction of the electrical transformers on the ships.

Because the container-ship category was so large, staff sought to find an appropriate subset of the data to illustrate the cost-effectiveness of the entire container-ship category. In this manner, the cost-effectiveness calculation method for container ships varied from the calculation methods used for the other ship categories. A complete discussion of the selection of the shipping companies, their associated terminals, and the cost-effectiveness calculations can be found in Appendix F.

At each port, cost-effectiveness values were determined for three scenarios: 1) all ships visiting the port are cold-ironed; 2) only ships that make three or more visits per year to a port are cold-ironed; and 3) only ships that make six or more visits per year to a port are cold-ironed. In addition, the cost-effectiveness scenarios consider whether the necessary electrical transformers are constructed at the port (shore-side) or on the ships (ship-side).

The cost-effectiveness scenarios also consider whether the auxiliary engines on the ships are burning two types of distillate fuel, as would be mandated by a recently adopted statewide regulation. This regulation requires, by January 1, 2007, the use of distillate fuel in a ship's auxiliary engines when the ship is within 24 nautical miles of California's coastline. Currently, distillate fuel has a sulfur content of 0.5 percent. By January 1, 2010, these auxiliary engines will be required to use 0.1 percent sulfur distillate fuel. Because the auxiliary engine regulation requires the use of distillate fuel by 2007, the fuel mix currently used by ships (mostly residual fuel) was not considered in the cost-effectiveness scenarios.

Tables G-1 and G-2 provide the cost-effectiveness values for container ships visiting POLA/POLB and Oakland, respectively, based on reducing all pollutants (NOx, PM, VOC, and SOx).

Table G-1: All Pollutants Cost Effectiveness for Cold-Ironing Container Ships at POLA/POLB (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
<u>All Ships</u>		
--ship-side transformer	$27,000-43,000	$31,000-49,000
--shore-side transformer	$12,000-18,000	$14,000-20,000
<u>Ships making 3 or more visits</u>		
--ship-side transformer	$23,000-28,000	$26,000-31,000
--shore-side transformer	$11,000-13,000	$13,000-15,000
<u>Ships making 6 or more visits</u>		
--ship-side transformer	$18,000-23,000	$20,000-26,000
--shore-side transformer	$9,500-15,000	$11,000-18,000

Table G-1 shows that, in every case, it is more cost effective to locate the transformers on the shore because a smaller number of transformers are required for the same level of service. For the specific terminals in this analysis, two to four shore-side transformers are needed, while 38 to 77 ship-side transformers are needed to accomplish the same task.

Also, note that the average cost-effectiveness values decrease as fewer ships are cold-ironed. This is true for most ship categories *up to a point*. When all ships are cold-ironed, ships making only one or two visits are included, and these ships have high cost-effectiveness values, driving up the average cost effectiveness. Conversely, if few ships are cold-ironed—say, ships making 12 or more visits—then the average cost-effectiveness starts to rise again. In this case, the cost of the shore-side infrastructure is allocated among fewer ships, adding to the expense of each visit. For example, 50 ships using $5 million worth of shore-side infrastructure is more cost effective per ship than only five ships using it. Furthermore, the average electrical rates increase for less overall activity because of demand charges, fees that are charged whether electricity is used or not.

Ideally, the berths that are the most attractive cold-ironing candidates are those that have a high utilization of ships who visit often. The worst candidate for cold-ironing is a berth that is rarely used, and then used by an occasional port visitor.

Finally, Table G-1 shows the cost-effectiveness impact of using cleaner distillate fuels. As discussed previously, the recently adopted regulation for auxiliary engines will require operators of ocean-going vessels to begin using distillate fuel (typically about 0.5 percent sulfur) in 2007 and very low-sulfur distillate fuel (0.1 percent sulfur) by 2010. The bulk of the reduction for the auxiliary engine regulation occurs when shipping companies are required to use distillate fuel instead of residual fuel. The use of very low-sulfur distillate fuel will further reduce the emissions of SOx by 20 percent and PM by 10 percent from current levels, thereby reducing the tons of “all pollutants” creditable to cold-ironing implementation.

Table G-2: All Pollutants Cost Effectiveness for Cold-Ironing Container Ships at the Port of Oakland (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$88,000-110,000	$100,000-120,000
--shore-side transformer	$41,000-52,000	$46,000-59,000
Ships making 3 or more visits		
--ship-side transformer	$78,000-98,000	$88,000-110,000
--shore-side transformer	$36,000-47,000	$41,000-54,000
Ships making 6 or more visits		
--ship-side transformer	$77,000-85,000	$87,000-96,000
--shore-side transformer	$37,000-44,000	$42,000-49,000

Table G-2 shows that the cost-effectiveness values for Oakland are considerably higher than those for POLA/POLB—about two to three times higher. This is primarily due to the lower hotelling times for ships that visit Oakland: 22 hours per visit versus 65 hours per visit for POLA/POLB. Consequently, cold-ironing seems much less attractive for Oakland.

However**,** 65 container ships that visited these three terminals at POLA/POLB in 2004 also visited Oakland (In total, of the 572 ships that visited POLA/POLB, 336 of these ships also visited Oakland). If these ships were retrofitted to cold-iron because of the cost-effectiveness of a project at POLA/POLB, and Oakland were to put in the necessary infrastructure to service these retrofitted ships, then the economics are more favorable for Oakland**.** Table G-3 provides the cost-effectiveness values for Oakland where the container ship costs are excluded because the ships had already been retrofitted to be cold-ironed at POLA/POLB.

Table G-3: All Pollutants Cost Effectiveness for Cold-Ironing Container Ships at the Port of Oakland without Container Ship Costs (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$14,000-17,000	$16,000-20,000
--shore-side transformer	$18,000-24,000	$20,000-27,000
Ships making 3 or more visits		
--ship-side transformer	$13,000-17,000	$15,000-19,000
--shore-side transformer	$17,000-23,000	$19,000-27,000
Ships making 6 or more visits		
--ship-side transformer	$14,000-17,000	$16,000-20,000
--shore-side transformer	$18,000-25,000	$21,000-28,000

Taking advantage of this synergism between ports, the cost-effectiveness values at Oakland are lower than those at POLA/POLB—in some cases over 50 percent lower. An anomaly of this synergism, however, is that the shore-side transformer scenarios are more expensive than the ship-side scenarios. If Oakland were to construct the necessary infrastructure to take advantage of ships already equipped for cold-ironing, it makes sense that the infrastructure would be less expensive if the transformers were already on the ships. The economics at POLA/POLB, as seen in Table G-1, suggest that the transformers would probably not be located on the ships.

Tables G-4 and G-5 provide cost-effectiveness values based upon the reductions of NOx emissions only for POLA/POLB and Oakland, respectively. Similar to the "all pollutants" analysis for POLA/POLB, the average cost-effectiveness values are highest when cold-ironing all the ships and lowest for the ships making six or more visits. Again, the shore-side transformer scenarios are much more cost effective—nearly half—than the ship-sides transformer scenarios.

Note that the use of either distillate fuel results in the same cost-effectiveness values, as they have the same NOx emission factors.

Table G-4: NOx Reduction Cost Effectiveness for Cold-Ironing Container Ships at POLA/POLB (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	\$33,000-52,000	\$33,000-52,000
--shore-side transformer	\$15,000-22,000	\$15,000-22,000
Ships making 3 or more visits		
--ship-side transformer	\$28,000-33,000	\$28,000-33,000
--shore-side transformer	\$13,000-16,000	\$13,000-16,000
Ships making 6 or more visits		
--ship-side transformer	\$22,000-28,000	\$22,000-28,000
--shore-side transformer	\$12,000-19,000	\$12,000-19,000

Table G-5: NOx Reduction Cost Effectiveness for Cold-Ironing Container Ships at the Port of Oakland (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	\$110,000-130,000	\$110,000-130,000
--shore-side transformer	\$49,000-63,000	\$49,000-63,000
Ships making 3 or more visits		
--ship-side transformer	\$94,000-120,000	\$94,000-120,000
--shore-side transformer	\$44,000-57,000	\$44,000-57,000
Ships making 6 or more visits		
--ship-side transformer	\$93,000-100,000	\$93,000-100,000
--shore-side transformer	\$44,000-53,000	\$44,000-53,000

Table G-5 shows that, again, average cost-effectiveness values at Oakland are substantially higher than those at POLA/POLB due to the much shorter berthing times.

However, Table G-6 shows that if the ships that visit POLA/POLB are retrofitted for cold-ironing and subsequently visit Oakland (i.e., the “free” ships case described earlier), then the cost-effectiveness values decrease by 50 to 80 percent.

Table G-6: NOx Reduction Cost Effectiveness for Cold-Ironing Container Ships at the Port of Oakland without Container Ship Costs (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
<u>All Ships</u>		
--ship-side transformer	$17,000-21,000	$17,000-21,000
--shore-side transformer	$22,000-29,000	$22,000-29,000
<u>Ships making 3 or more visits</u>		
--ship-side transformer	$15,000-20,000	$15,000-20,000
--shore-side transformer	$20,000-28,000	$20,000-28,000
<u>Ships making 6 or more visits</u>		
--ship-side transformer	$17,000-21,000	$17,000-21,000
--shore-side transformer	$22,000-30,000	$22,000-30,000

Tables G-7 and G-8 contain the cost-effectiveness values based upon PM emission reductions only for both POLA/POLB and Oakland, respectively. The cost-effectiveness values on a PM-reduction only basis are large because the use of distillate fuel significantly reduces the amount of diesel PM creditable for cold-ironing. Otherwise, the cost-effectiveness values exhibit the same trends as seen in the earlier analyses.

Table G-9 shows the scenario where the retrofitted ships visit Oakland, and Oakland installs the necessary infrastructure to accommodate them. Again, the economics are more favorable for this synergistic case, although the values remain high.

Table G-7: PM Reduction Cost Effectiveness for Cold-Ironing Container Ships at POLA/POLB (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
<u>All Ships</u>		
--ship-side transformer	$1,200,000-2,000,000	$1,900,000-3,000,000
--shore-side transformer	$560,000-810,000	$870,000-1,300,000
<u>Ships making 3 or more visits</u>		
--ship-side transformer	$1,100,000-1,300,000	$1,600,000-2,000,000
--shore-side transformer	$500,000-590,000	$770,000-920,000
<u>Ships making 6 or more visits</u>		
--ship-side transformer	$830,000-1,000,000	$1,300,000-1,600,000
--shore-side transformer	$430,000-700,000	$670,000-1,100,000

Table G-8: PM Reduction Cost Effectiveness for Cold-Ironing Container Ships at the Port of Oakland (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
<u>All Ships</u>		
--ship-side transformer	$4,000,000-5,000,000	$6,200,000-7,700,000
--shore-side transformer	$1,800,000-2,300,000	$2,800,000-3,600,000
<u>Ships making 3 or more visits</u>		
--ship-side transformer	$3,500,000-4,400,000	$5,500,000-6,900,000
--shore-side transformer	$1,600,000-2,100,000	$2,600,000-3,300,000
<u>Ships making 6 or more visits</u>		
--ship-side transformer	$3,500,000-3,800,000	$5,400,000-5,900,000
--shore-side transformer	$1,700,000-2,000,000	$2,600,000-3,100,000

Table G-9: PM Reduction Cost Effectiveness for Cold-Ironing Container Ships at the Port of Oakland without Container Ship Costs (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$630,000-780,000	$980,000-1,200,000
--shore-side transformer	$810,000-1,100,000	$1,200,000-1,700,000
Ships making 3 or more visits		
--ship-side transformer	$580,000-760,000	$900,000-1,200,000
--shore-side transformer	$750,000-1,100,000	$1,200,000-1,700,000
Ships making 6 or more visits		
--ship-side transformer	$620,000-790,000	$960,000-1,200,000
--shore-side transformer	$830,000-1,100,000	$1,300,000-1,800,000

The prior analyses have all addressed *average* cost effectiveness. As mentioned before, when cold-ironing all ships, these average values include many ships that visit a few times and a few ships that visit many times. The following analysis will address the cost effectiveness of cold-ironing an incremental ship if the shore-side infrastructure is already in place.

Table G-10 provides incremental cost-effectiveness values for NOx reductions only, PM reductions only, and “all pollutants.” These values are based on a 3,900 TEU container ship, a moderate size, visiting POLA/POLB. Also, the calculations are based upon the auxiliary engines using the very low sulfur distillate fuel, the necessary transformer is located on shore, and the ship berths at the port for 40 hours for each visit—typical for this size ship. The average electrical rate assumes that there is already sufficient cold-ironing activity at the berth to minimize the effect of demand charges.

Not surprisingly, the cost-effectiveness values decrease with the increasing number of trips. What is important to note is that while the *average* cost effectiveness for cold-ironing all ships on a NOx-only basis (Table G-4) is $15,000 to $22,000 per ton, the incremental cost of cold-ironing one ship is $96,000 per ton. It is not until a ship makes about five visits until the incremental cost effectiveness approaches the average cost effectiveness.

As discussed before, average cost-effectiveness values are higher if all ships are cold-ironed because the one-time visitors are included. These ships represent the “$96,000” incremental ships. So while the *average* cost effectiveness may look reasonable for all ships, there are ships within that group that will require further review before they can be considered for cold-ironing.

Table G-10: Incremental Cost Effectiveness to Retrofit a Typical Container Ship Using Distillate Fuel (0.1 percent sulfur) (Dollars/ton)

Visits	NOx	PM	All Pollutants
1	$96,000	$5,600,000	$90,000
2	$50,000	$2,900,000	$47,000
3	$35,000	$2,000,000	$33,000
4	$27,000	$1,600,000	$26,000
5	$23,000	$1,300,000	$22,000

Table G-11 provides the cost-effectiveness values for a large container ship, carrying 6,000-7,000 TEUs. Table G-11 reflects a ship using distillate fuel (0.1 percent sulfur and the calculations assume the transformer is located on the shore. Based upon responses from shipping companies to ARB's Ocean-Going Vessel Survey, ships of this size stay in port longer—in this case, about 75 hours per visit. As shown in this table, the incremental cost-effectiveness values are much lower, similar to the average cost-effectiveness values given earlier in the chapter. The incremental cost-effectiveness values are substantially lower for larger container ships because they use more power and therefore emit more pollutants, and the larger ships tend to stay in port longer than smaller ships.

Table G-11: Incremental Cost Effectiveness to Retrofit a Large Container Ship Using Distillate Fuel (0.1 percent sulfur) (Dollars/ton)

Visits	NOx	PM	All Pollutants
1	$32,000	$1,900,000	$30,000
2	$18,000	$1,000,000	$17,000
3	$13,000	$760,000	$12,000

Table G-11 suggest that a large container ship may be cost-effective to cold-iron for only one trip if the shore-side infrastructure is in place and the berth is sufficiently active to have lower electrical rates.